APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: PIXEL OPTIMIZATION FOR COLOR

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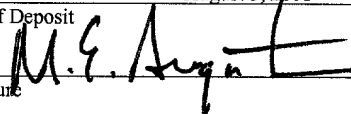
PIXEL OPTIMIZATION FOR COLOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of the filing date of U.S. provisional application No. 60/223,396 filed August 7, 2000, the content of which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates generally to image sensors and in particular, to complementary metal oxide semiconductor (CMOS) color image sensors.

BACKGROUND AND SUMMARY

[0003] Conventional imaging circuits typically use active pixel sensor cells to convert light energy into electrical signals. Each of the active pixel sensor cells generally includes a photoreceptor with several associated transistors that provide several pixel functions including signal formation, reset, and amplification. In a color imager, separate pixels are used for receiving each band of light, such as those corresponding to the primary colors, red, green, and blue. The responsivity of a pixel varies with the specific color of light that is being captured. For example, in a system employing red, green, and blue color pixels, having a uniform integration time for each pixel and a typical scene being imaged; the output signal of a pixel for an amount

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of light received will vary as a function of the responsivity of the pixel to the imaged color. Correspondingly, the signal to noise ratio (S/N) of the pixels will vary as a function of the responsivity to the imaged color. Typically, blue pixels are less responsive than red and green pixels, causing the S/N of the blue pixels to be less than the S/N of red and green pixels. In addition to differences in S/N, there are differences in saturation of the pixels. Specifically, when capturing an image with equal amounts of red, green, and blue light, the storage capacitance associated with the pixels having the greater sensitivity (the red and green pixels) will reach a maximum capacity of stored photoelectrons first, saturating the pixel.

[0004]   Separate gain elements for corresponding spectral band channels can be used to equalize the output signals of the different color sensors to compensate for differences in responsivity. However, the gain elements increase the cost of the imager, require increased space, and have no effect on the differences in S/N for the different color pixels.

[0005]   A macro pixel is provided. The macro pixel includes at least two color pixel elements. Each color pixel element includes a photoreceptor that in response to receiving light, generates an output signal that is indicative of the quantity of light photons received. A first of the color pixel

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elements is configured to receive a first color. The

photoreceptor of the first of the color pixel elements has a

first geometry and a responsivity to light that is a function

of the first geometry of the photoreceptor such that the

responsivity of the output signal of the photoreceptor to the

first color is controllable by changing the first geometry. A

second of the color pixel elements is configured to receive a

second color. The photoreceptor of the second of the color

pixel elements has a second geometry and a responsivity to

light that is a function of the second geometry such that the

responsivity of the output signal of the photoreceptor to the

second color is controllable by changing the second geometry.

[0006]   The details of one or more embodiments of the

invention are set forth in the accompanying drawings and the

description below. Other features, objects, and advantages of

the invention will be apparent from the description and

drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0007]   FIG. 1 is a two-dimensional view of a color pixel

assembly in accordance with the principles of the invention;

[0008]   FIG. 2 is a two-dimensional view of a first series

of color pixel elements;

[0009]   FIG. 3 is a two-dimensional view of a second series

of color pixel elements;

[0010]   FIG. 4 is a set of graphs illustrating data associated with first and second series of color pixel elements;

[0011]   FIG. 5 is a view of a pair of color pixel elements with corresponding microlenses; and

[0012]   FIG. 6 is a two-dimensional view of a series of color pixel elements having active switches.

[0013]   Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0014]   An embodiment of a color imaging system 10 in accordance with the teachings of the invention is shown in Figure 1. The color imaging system 10 includes an array of macro pixels 12, each converting received light into an electrical output signal. Each macro pixel 12 is preferably comprised of two green pixels 14a and 14b, a red pixel 18, and a blue pixel 16 that are configured in a Bayer pattern. Although a Bayer pattern pixel configuration is preferable, other pixel configurations that include two or more different color pixels including non-primary colors may be used.

[0015]   The output signal of each color pixel is described by the following equation:

$$V_n \ \alpha \ phi_n \ * \ T_n \ * \ A_n \ * \ eta_n \ * \ G_n$$

where n = 1, 2, 3 ... is the spectral band (e.g., 3 bands in the case of RGB), phi_n is the flux per unit area of each pixel, T_n is the transmission of each spectral band filter, A_n is the collection area of each pixel, eta_n is the quantum efficiency of each pixel, and G_n is the conversion gain of each pixel.

[0016]   The invention may compensate for differences in responsivity between different color pixels (e.g. red versus green), to control the relative sensitivity of the signal outputs, V_n, to phi_n, while maintaining relatively equal pixel area for each color pixel. To compensate for differences in responsivity, the shape of the photoreceptor, e.g. the shape of the photodiode, for each type of color pixel, is adjusted. The photodiode shapes are selected so that the relative sensitivity of V_n to phi_n for the signal outputs is a predetermined ratio such as 1:1:1 for a CMOS RGB color image system.

[0017]   Other photoreceptors such as n+ diffusion photodiodes, standard n-well photodiodes, and n-well photodiodes with a covering insulating field oxide as described in U.S. Patent No. 6,040,592, p+ diffusion photodiodes, p-well photodiodes, and p-well photodiodes with a covering insulating field oxide, photogates, and other devices

may be used. The generation of photocurrent in both the

diffusion and well type photodiodes is similar. In each, a

depletion region is formed across and near the p-n junction

formed by the substrate and the diffusion area/well. Incident

photons pass through an open portion of the photodiode surface

area and impinge on the depletion area, generating

photoelectrons. The generated photoelectrons are accumulated

on the capacitance formed by the depletion area of the

photodiode. The photoelectrons are swept out as a

photocurrent when a reverse voltage is applied across the p-n

junction.

[0018]   Figures 2 and 3 show a two-dimensional view of a

series of color pixels 20a-20h. The series of color pixels

20a-20h is used for matching the light sensitivity of

different pixel configurations to the light color that a pixel

measures. Although eight pixel configurations are chosen for

the present example, any number of pixel configurations may be

chosen. Each of the color pixels 20a-20h in the series is

constructed to have a pixel area that is substantially a

constant, in this case about 4.4 * 4.4 sq. um., with differing

types of photodiodes 22a-22h that have varying shapes. The

geometric shape and type of the photodiodes 22a-22h is varied

to determine which color pixels 20a-20h to match with which

colors to obtain output signals having a predetermined light

sensitivity. In this example, color pixels 20a-20d are selected to have n-well photodiodes with variable diameter collector areas that are spaced a predetermined distance from the sidewall of the color pixel. Color pixels 20e-20h are selected to have n+ diffusion photodiodes in which the area of the collector is varied and the distance of the photodiode from the sidewall is controlled. The spectral responsivity versus wavelength and quantum efficiency versus wavelenth for each of the color pixels may be measured. In addition to varying the surface area of the collectors, other portions of the photodiode geometry that may be varied include the depth of the diffusion or well, and the spacing from the sidewall of the color pixel 20.

[0019] Figure 4 shows graphs of the measured spectral responsivity versus wavelength and quantum efficiency versus wavelenth of the eight color pixels 20a-20h are shown. The quantum efficiency, QE, is computed with respect to the total sensor area. As the photodiode area gets larger, the QE increases. In general, due to inherent advantages of N-well design over N+ diffusion photodiodes, N-well pixels demonstrate equal or lower capacitance and, correspondingly, equal or higher gain. Also, the capacitance is greater for pixels with larger photodiode area and longer sidewall perimeter. Also, N-well photodiodes show a higher QE and lower

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dark current density than the N+-diffusion photodiodes.   Based

on the measured data, color pixels are selected for each

spectral band.

[0020]   Figure 1 shows the illustrated macro pixel

configured to have a 1:1:1 relative sensitivity for a RGB CMOS

imager 10.   The macro pixel 12 includes color pixel 20b for

the green color pixels 14a and 14b, color pixel 20a for the

blue color pixel 16, and color pixel 20c for the red color

pixel 18.   The macro pixel 12 may alternatively include color

pixel 20f for the green color pixels 14a and 14b, color pixel

20d for the blue color pixel 16, and color pixel 20h for the

red color pixel 18.

[0021]   Figure 5 shows a pair of color pixel elements 30 and

32 with corresponding microlenses 34 and 36.   Using a

microlens improves the fill factor of a pixel.   The microlens

redirects light that would have reached the edges of the pixel

into a focal area such as the center of the pixel or the

photodiode collector area.   By redirecting the light from the

edges, the quantum efficiency for a color pixel element

remains constant for different photodiode shapes and sizes.

To vary the responsivity of a pixel element having a

microlens, the conversion gain, G_{conv}, may be varied.   One

method of varying G_{conv}, is to vary the photodiode collector

area, since G_{conv} is inversely proportional to the collector area.

[0022]   Figure 6 shows a two-dimensional view of a series of color pixel elements with a first alternate embodiment of the present invention. The pixels 20i-20k include n+ diffusion photodiodes in which the area 22i-22k of the collector may be actively varied by controlling one or more switches 23i-23k. By activating one of the switches 23i-23k the geometry of the photodiodes changes, causing the responsivity of the corresponding pixels 20i-20k to change in a controlled manner. The switches 23i-23k may be actively controlled during normal operation or may be fusible links that are set during a configuration procedure.

[0023]   A number of embodiments of the invention have been described. It is expressly intended that the foregoing description and accompanying drawings are illustrative of preferred embodiments only, not limiting, and that the true spirit and scope of the present invention will be determined by reference to the appended claims and their legal equivalent. It will be equally apparent and is contemplated that various modifications and/or changes may be made in the illustrated embodiments without departure from the spirit and scope of the invention.